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Radiation Effects in Glasses for Intrinsic Optical Fibre Radiation Dosimetry

by

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A thesis submitted in fulfillment of the degree of Doctor of Philosophy

in the

Faculty of Sciences

School of Chemistry and Physics

University of Adelaide, Australia

August 2015

Abstract

An optical fibre device has been developed for the purpose of detecting ionising radiation using optically stimulated luminescence. Characterisation of glass materials has been performed, after which optical fibres were fabricated for experiments to demonstrate sensing of ionising radiation.

Fluoride phosphate glass was tested for its capability to sense ionising radiation, primarily using the mechanism of optically stimulated luminescence. The characteristics of the material were determined using a combination of spectroscopy, and thermally and optically stimulated luminescence tests. The sensitivity to ionising radiation was improved by introducing dopant ions into the glass; doping of fluoride phosphate glass with Tb^{3+} was found to increase the intensity of the optically stimulated luminescence response by an order of magnitude, from 7.56×10^6 counts/g/Gy to 100.7×10^6 counts/g/Gy.

Optical fibres were fabricated from fluoride phosphate glass using the extrusion method for fibre preform manufacture. The fabrication process was optimised in each of the extrusion, preform processing and fibre drawing stages to achieve optical fibres with loss of between 0.5 - 1 dB/m for undoped fibres, and between 1 - 4 dB/m for Tb^{3+} -doped fibres. Optical fibres were used for ionising radiation sensing experiments, where the optically stimulated luminescence response was measured following both beta and X-ray irradiation. Following a dose of 14.6 ± 0.5 Gy, optically stimulated luminescence signals were observable using optical fibre lengths of up to 2.6 m, with an integrated OSL intensity of 44.1 ± 13.0 counts.

Silica glass was also tested as an alternative material to perform optical fibre measurements using optically stimulated luminescence. The material was characterised and optical fibres were fabricated with a loss of 0.5 dB/m. Following a dose of 15.5 ± 0.5 Gy, optically stimulated luminescence signals were observable using optical fibre lengths of up to 8.6 m, with an integrated OSL intensity of 385.7 ± 43.4 counts.

Declaration

I, Christopher A. G. Kalnins, declare that this thesis titled ‘Radiation Effects in Glasses for Intrinsic Optical Fibre Radiation Dosimetry’ and the work presented in it are my own.

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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Acknowledgements

Firstly I would like to thank my supervisors: Heike Ebendorff-Heidepriem, Nigel Spooner and Tanya Monro. Your patience and guidance through each stage of this work has been invaluable and without it, this thesis would not exist.

For their technical support, I wish to thank Alastair Dowler, Herbert Foo, Kevin Kuan, Rachel Moore, Kenton Knight, Peter Henry and Donald Creighton. Your assistance with fibre drawing, glass and preform fabrication, and 3D thermoluminescence spectrometry has been invaluable.

The Institute for Photonics and Advanced Sensing and The School of Chemistry and Physics have been instrumental in creating a fantastic working environment, both professionally and socially. In particular I would like to express my pleasure to have worked within the Environmental Luminescence, Chemical and Radiation Sensing, and Fabrication groups.

For their financial support and usage of equipment and facilities, I would like to thank the Defence Science and Technology Organisation. For usage of fabrication facilities, the South Australian node of the Australian National Fabrication Facility is also acknowledged.

On a personal note, I would like to extend my gratitude to my family who have supported and encouraged me not just through this thesis, but through my whole life. Mum, Dad and Nici, you've been an inspiring family to grow up in.

For bringing not only fun and warmth, but also a strong feeling of belief and encouragement, my gratitude goes out to Antonija. Thank you for being by my side.

For their dark and bitter humour, without which I could not have seen the bigger picture of life, I must thank all my friends. I appreciate every single one of you and what you bring into my life. Many of you are also pursuing research degrees, and I have enjoyed the solidarity as we question our life choices.

Lastly and perhaps most importantly, I would like to acknowledge EDM, chocolate and the peace found at 2 am.

Contents

Abstract	i
Declaration	i
Acknowledgements	ii
Table of Contents	iii
Summary	ix
List of Figures	xi
List of Tables	xxiii
1 Introduction	1
1.1 Introduction to Radiation Dosimetry	2
1.1.1 History of Dosimetry	2
1.1.2 Examples of Dosimetry	2
1.2 State-of-the-Art of Optical Fibre-Based Radiation Sensing	4
1.2.1 Radioluminescence	5
1.2.2 Photodarkening	6
1.2.3 Thermoluminescence	6
1.2.4 Bragg Gratings	7
1.2.5 Optically Stimulated Luminescence	7
1.2.6 Comparison of Extrinsic and Intrinsic Sensing Methods	8
1.2.7 Advantages of Fibre-Based Sensing	9
1.3 Luminescence Theory	10
1.3.1 Optically Stimulated Luminescence	10
1.3.2 Thermoluminescence	14
1.4 Dose Deposition Within Materials	16
1.4.1 Photon Interactions	18
1.4.2 Electron and Positron Interactions	18

1.4.3	Radiation Sources	19
1.5	Simulation of Energy Deposition	22
1.5.1	Motivation	22
1.5.2	Simulation Package and Theory (PENELOPE)	22
1.5.3	Physical Processes Simulated by PENELOPE	23
1.5.4	Abilities and limitations	23
1.6	Project Constraints and Opportunities	24
1.6.1	Glass Fabrication Facilities	24
1.6.2	Detection Systems	24
1.7	Comparison of Detectors	25
1.8	Thesis Overview	26
2	Identification and Characterisation of Fluoride Phosphate Glass	30
2.1	Initial Survey of Glass Characteristics	31
2.1.1	Glass Samples	31
2.1.2	Screening for Optically Stimulated Luminescence	31
2.2	Fluoride-phosphate Glass	33
2.2.1	Varieties of Fluoride Phosphate Samples	33
2.3	Composition	34
2.3.1	Electron Microprobe	34
2.3.2	ICP-MS/OES	36
2.4	Transmission Spectra and Photodarkening	36
2.4.1	Effect of Photodarkening	37
2.4.2	Emission Spectra	40
2.5	Redox State of Fluoride Phosphate Glass	41
2.6	Luminescence Characterisation of Fluoride Phosphate Glass	41
2.6.1	Thermoluminescence Measurements	42
2.6.2	Optically stimulated luminescence	46
2.7	Simulations of Radiation Penetration and Dose Deposition	53
2.7.1	Stopping Power	54
2.7.2	Energy Transfer	54
2.7.3	Range of Electrons	56
2.7.4	Dose Deposition Profiles	57
2.8	Summary	58
3	Fabrication and Characterisation of Doped Fluoride Phosphate glass	60
3.1	Choice of Dopant Ions	61
3.2	Fabrication of Doped Fluoride Phosphate Glasses	61
3.2.1	Oxidising Atmosphere	62

3.2.2	Reducing Atmosphere	62
3.2.3	Sample Summary	63
3.3	Spectroscopy	63
3.3.1	Copper	64
3.3.2	Manganese	64
3.3.3	Terbium	64
3.3.4	Radioluminescence Spectra	67
3.4	Optically and Thermally Stimulated Luminescence Measurements	68
3.4.1	Copper	71
3.4.2	Manganese	73
3.4.3	Terbium	76
3.4.4	Summary	81
3.5	Anomalous Fading	83
3.5.1	Theory	83
3.5.2	Experiment to Detect and Observe Anomalous Fading	83
3.5.3	Results	85
3.6	Summary of Dopant Properties	86
4	Fabrication of Fluoride Phosphate Optical Fibres	88
4.1	Introduction	89
4.1.1	State-of-the-Art	89
4.1.2	Glass Material	89
4.1.3	Fibre Geometry	89
4.2	Extrusion	90
4.2.1	Die Materials	91
4.2.2	Extrusion Force, Speed and Temperature	91
4.2.3	Limit on Extrusion Temperature	93
4.2.4	Atmosphere	94
4.3	Preform Treatment	94
4.3.1	Energy Dispersive X-ray Spectroscopy	94
4.3.2	Optical Profiling	95
4.3.3	Chemical Etching	96
4.3.4	Mechanical Polishing	98
4.4	Fibre Fabrication	101
4.4.1	Fibre Characterisation	101
4.4.2	Fibre Drawing	101
4.5	Summary of Optical Fibre Quality	103
4.6	Doped Fluoride Phosphate Optical Fibres	105
4.7	Fibre Jacketing	108

4.8	Summary	112
5	Detection of Optically Stimulated Luminescence in Optical Fibres	113
5.1	Dose Deposition and Radiation Considerations	114
5.1.1	Radiation Safety	114
5.1.2	Dose Deposition Profiles	115
5.1.3	Calculation of Dose Deposition in Fibres	115
5.2	Detectors, Optical Stimulation and Filters	118
5.2.1	Detection with a PMT	118
5.2.2	Detection with a SPAD	121
5.2.3	Luminescence in the 350 - 600 nm region	123
5.3	Development of an Experimental Test-Bed	125
5.3.1	Differences Between Bulk and Fibre Measurements	126
5.3.2	Signal Detection and Integration	127
5.3.3	Improvements in Signal-to-Noise Ratio	127
5.3.4	Optical Alignment	135
5.4	OSL Measurements	137
5.4.1	Stimulation Power	137
5.4.2	OSL with respect to dose	137
5.4.3	Minimum Fibre Size and Mass	140
5.4.4	Summary	140
5.5	OSL Measurements on Tb ³⁺ -Doped Optical Fibres	142
5.5.1	OSL Tests on Tb ³⁺ -Doped Fibre Melted in Reducing Atmosphere	142
5.5.2	OSL Tests on Tb ³⁺ -Doped Fibre Melted in Oxidising Atmosphere	144
5.5.3	Summary	146
5.6	Detection of X-rays	148
5.6.1	Experimental Setup	148
5.6.2	Results	150
5.7	Summary	157
6	Investigation of the Radiation-Detecting properties of Silica Optical Fibres	159
6.1	Introduction	160
6.2	Silica Glass Samples	160
6.2.1	Fluorescence Emission	161
6.3	Thermally and Optically Stimulated Luminescence Measurements	161
6.3.1	Optically Stimulated Luminescence	161
6.3.2	Thermoluminescence	163

6.3.3	Thermoluminescence Emission Spectrometry	165
6.3.4	Initial Rise Thermoluminescence	165
6.4	OSL in Silica Fibres and Canes	167
6.4.1	Fabrication of Silica Fibres and Canes	167
6.4.2	OSL in Optical Fibres	170
6.4.3	Dose Dependence	171
6.4.4	X-ray Irradiation	173
6.5	Comparison of Silica and Fluoride Phosphate Glasses	180
6.5.1	Transmission Loss	180
6.5.2	Mechanical Strength and Jacketing	180
6.5.3	Thermal Properties	181
6.5.4	Trap Lifetime	181
6.5.5	Doping of Glasses	181
6.5.6	Luminescence	182
6.5.7	Bleaching and Re-usability	184
6.6	Conclusions	184
7	Discussion, Conclusions and Future Work	185
7.1	Summary of Experimental Work and Key Results	186
7.2	Trap Lifetime of Fluoride Phosphate Glass	187
7.3	Feasibility of the Optical Fibre Sensor	188
7.4	With Respect to the State of the Art	191
7.5	Alternative Ideas for Optical Fibre Dosimetry	192
7.6	Future Directions	194
7.7	Conclusions	197
	Appendices	212
A	Materials and Materials Properties	213
A.1	Initial Glass Screening	213
A.2	Fluoride Phosphate Glasses	215
A.2.1	Summary of FP Glass Samples	215
A.2.2	Schott N-FK51A Fluoride Phosphate Glass	216
A.3	ICPMS/OES Detection Limits	218
A.4	Silica Glass	219
A.5	Fluoride Phosphate Glass Radiation Interaction Values	220
B	Instrumentation and Fabrication Facilities	226
B.1	Risø TL/OSL DA-20 Reader	226
B.1.1	Sample Preparation	226

B.1.2	Sample Irradiation	227
B.1.3	Luminescence Detection	227
B.2	Glass Fabrication	228
B.3	Extrusion Machine	228
B.4	Fibre Draw Tower	230
C	Fabrication Data	234
C.1	Extrusion Data	234
C.2	Fibre Drawing Data	234
D	PENELOPE Simulations	236
D.1	Stopping Power Calculations	236
D.2	Electron and Photon Absorption in FP Glass	236
D.3	Examples of Simulation Input Files	239

Summary

This thesis contains a study of the feasibility of detecting ionising radiation with an optical fibre, specifically using the mechanism of optically stimulated luminescence. This work addresses the particular case where the radiation sensing occurs within the optical fibre material, and not in a separate material otherwise spliced to a fibre. The optical fibre therefore acts as both the sensing component of the device, and the wave-guiding component which carries a signal to the detector. This work fills a void in the already-established range of optical fibre dosimetry technologies, and provides an alternative method for performing optical fibre dosimetry.

To achieve the project goals, glass materials were studied for their optical, luminescence and radiation detecting properties. These glasses were then fabricated into optical fibres, and these fibres tested in a variety of radiation environments. Work was initially performed with fluoride phosphate glasses, where the glass was characterised and then altered by the addition of various dopant ions to improve its radiation detecting sensitivity. Silica glasses were later studied as a comparison to fluoride phosphate glasses. Also presented is the fabrication of these glass materials into optical fibres of suitable quality to perform distributed sensing measurements of ionising radiation. The performance of the optical fibres are studied under both beta and X-ray irradiation conditions, and their usefulness as dosimeter devices is assessed.

Chapter 1 outlines the context and motivation behind the presented work, and provides a short introduction to the theory behind the experimental work. *Chapter 2* explores the various properties of the materials used for optical fibre fabrication, primarily focusing on fluoride phosphate glasses. In *Chapter 3*, the modification of fluoride phosphate glasses with dopant ions in order to improve the sensitivity as a radiation detecting material is presented. *Chapter 4* presents the fabrication of the radiation sensitive material into optical fibres of sufficient mechanical strength and optical quality for radiation sensing experiments. The radiation sensing experiments for which these optical fibres were used are shown in *Chapter 5*. *Chapter 6* presents an alternative material, silica, and shows how in some areas it can be superior to the materials discussed in previous chapters. *Chapter 7* summarises the experimental work and gives an appraisal on

the feasibility of using this novel method of radiation sensing in real-world applications; this is followed by a summary of future directions for this area of research.

List of Figures

1.1	Extrinsic (top) and intrinsic (bottom) optical fibre architectures. Red indicates the region over which the radiation sensing phosphor is active.	8
1.2	Mechanism of optically stimulated luminescence, showing 1) dose deposition 2) electron trapping and 3) stimulation and recombination. Ionising radiation is shown in red, optical stimulation in green and stimulated luminescence emission in blue.	10
1.3	(1) Ionising radiation deposits energy. (2) Luminescence is emitted in 4π (blue), only a fraction is captured by the guided modes of the fibre (darker blue). (3) This captured luminescence is guided in each direction down the fibre.	12
1.4	Integrated area of OSL signal.	13
1.5	Mechanism of thermoluminescence, showing 1) dose deposition 2) electron trapping and 3) thermal stimulation and recombination. Ionising radiation is shown in red, thermal stimulation by a campfire and the stimulated luminescence in blue.	15
1.6	Glow peaks of a thermoluminescence ‘glow curve’, showing where data may be integrated to analyse a given peak. Red lines indicate the region used for ‘initial rise’ TL measurements. The sharp rising feature at higher temperature is a depiction of the incandescence signal.	16
1.7	Electron (top) and photon (bottom) showers in silicon dioxide, each for 2.28 MeV primary energy. Data was simulated using PENELOPE, the process of which is explained in Section 1.5.	17
1.8	Interactions of photons with matter.	19
1.9	Interaction of electrons with matter.	20
1.10	Representation of a typical bremsstrahlung spectrum. Table inset lists the energies of the K_α and K_β characteristic X-ray peaks for tungsten.	21
1.11	Quantum efficiency of a PMT (EMI 9235 QB) compared with two single photon avalanche diodes, Micro Photon Devices (MPD) and Lasercomponents (COUNT [®] -blue).	27

1.12	Overview of experimental process from the initial glass analysis through to radiation sensing measurements with optical fibres. Blue lines: chronological timeline of experiments. Red lines: experimental results used to guide analysis and fabrication of new materials and fibres.	29
2.1	Example of an OSL response from a variety of the glass samples examined.	32
2.2	Composition of fluoride phosphate glasses as determined by an electron microprobe. Data was taken from multiple points on the glass surface for each sample.	35
2.3	Transmission spectra of several different samples of FP glass, taken using 1 mm thick polished slides.	38
2.4	Photodarkening in Schott N-FK51A fluoride phosphate glass over 7 hours due to irradiation with a $^{90}\text{Sr}/^{90}\text{Y}$ Beta source.	39
2.5	Annealing of colour centers by heat treatment at 200 °C for 2 hours. . .	39
2.6	Emission spectra of several FP glass samples.	40
2.7	Thermoluminescence of FP1 glass melted in different redox conditions. .	43
2.8	Initial rise thermoluminescence for Schott N-FK51A fluoride phosphate glass.	44
2.9	Calculation of the slope for $\ln(I)$ vs. $1/T$, from which values for E , s and τ are extracted.	44
2.10	Thermoluminescence emission spectrum of undoped FP1 glass. Top = ambient melting conditions, bottom = reducing melting conditions. . . .	46
2.11	Complete bleaching of FP1 and FP1red glass in both the 275 - 400 nm and 350 - 600 nm wavebands, using 470 nm and 870 nm optical stimulation respectively. Results are given for different bleaching times between measurements, 5 s and 30 s, the optical power incident on each sample is shown in the legend. Lines are provided only as a guide for the eye.	50
2.12	OSL signal of fluoride phosphate glass as a function of the applied dosage. Trendlines indicate a linear response from 0 - 2 Gy, and an exponential response from 2 - 30 Gy.	51
2.13	(a) $\ln(I/I_0)$ vs. t and (b) $(I/I_0)^{(1-b)/b}$ vs. t . Data shown is for measurements taken at ambient temperature on FP1 glass.	52
2.14	OSL with respect to the stimulation power of the diode arrays in the Risø Reader.	53
2.15	Stopping power of fluoride phosphate glass over a range of particle energies.	54
2.16	Simulated energy absorbed from a 2.28 MeV electron beam (left) and a 100 keV photon beam (right) by layers of FP glass with varying thickness.	55

2.17	Simulated energy of transmitted primary particles from a 2.28 MeV electron beam (left) and a 100 keV photon beam (right) by layers of FP glass with varying thickness. Simulation was performed using PENELOPE.	56
2.18	Dose deposition profile of a parallel electron beam into fluoride phosphate glass.	58
2.19	Dose deposition profile of a parallel photon beam into fluoride phosphate glass.	59
3.1	Emission spectra of sample Cu-red-60 under a reducing environment, copper concentration is 60 ppmwt.	65
3.2	Absorption spectra of FP1 glass doped with copper ions and melted under ambient and reducing atmospheres.	65
3.3	Emission spectra of FP1 glass doped with manganese.	66
3.4	Absorption spectra of FP1 glass doped with manganese and melted under ambient and reducing atmospheres.	66
3.5	Emission spectra of sample Tb-red. Excitation at 355 nm with a mercury lamp and a frequency tripled YAG laser.. . . .	67
3.6	Absorption spectra of FP1 glass doped with Tb ³⁺ and melted under ambient and reducing atmospheres.	69
3.7	Experimental setup for measuring the spectra of RL from bulk glass samples.	69
3.8	RL spectra of Schott N-FK51A fluoride phosphate glass. Excitation with a 320 MBq ⁹⁰ Sr/ ⁹⁰ Y beta source, described in Section 5.1.	70
3.9	TL spectra of fluoride phosphate glasses doped with copper under ambient and reducing atmospheres.	71
3.10	Thermoluminescence emission spectrum of sample Cu-red, 3D and intensity contour plots.	72
3.11	OSL shine-down trace for copper doped FP glass compared with undoped glass, produced under both oxidising and reducing conditions. Copper concentration is 60 ppmwt for each doped sample. Above: OSL detected using 470 nm optical stimulation and a HOYA U340 filter. Bottom: OSL detected using 870 nm optical stimulation and a Schott BG39 filter.	74
3.12	Integrated OSL counts from FP1 glass doped with Cu ⁺ under a reducing environment. Lines are included only as a guide for the eye.	75
3.13	TL emission of Mn ²⁺ doped FP glass.	75
3.14	Thermoluminescence emission spectrum of sample Mn-ox, shown as both 3D and intensity-contour plots to highlight the dominance of 600 nm Mn ²⁺ emission.	76

3.15	OSL shine-down trace for manganese doped FP glass compared with undoped glass, produced under both oxidising and reducing conditions. Manganese concentration is 2749 ppmwt for each doped sample. Above: OSL detected using 470 nm optical stimulation and a HOYA U340 filter. Bottom: OSL detected using 870 nm optical stimulation and a Schott BG39 filter.	77
3.16	TL emission of Tb ³⁺ -doped FP glass.	78
3.17	Thermoluminescence emission spectrum of sample Tb - red, 3D and intensity contour plots. The series of peaks seen for fluorescence and scintillation measurements are also clearly visible in the 400 – 600 nm region.	79
3.18	OSL shine-down trace for terbium doped FP glass compared with undoped glass, produced under both oxidising and reducing conditions. Terbium concentration is 7200 ppmwt for each doped sample. Above: OSL detected using 470 nm optical stimulation and a HOYA U340 filter. Bottom: OSL detected using 870 nm optical stimulation and a Schott BG39 filter.	80
3.19	Reproducibility of sample Tb-ox glass with different ‘bleaching’ periods between individual OSL measurements. One set of measurements is taken using 5 s (167.2 mJ) of optical stimulation at 870 nm and the other with 100 s (1672 mJ). Measurements were taken using a Schott BG39 filter. Lines are included only as a guide for the eye.	81
3.20	Plot of the OSL data provided in Table 3.4, shown for both 275 – 400 and 350 – 600 nm wavelength regions. Results shown for samples fabricated under both oxidising and reducing conditions.	82
3.21	Anomalous fading of undoped and doped FP glasses following a one hour pause after irradiation.	84
3.22	Luminescence from sample Mn-ox, following irradiation and pre-heat to 230 °C. Sample receives no stimulation during data collection; the sample was held at ambient temperature for this measurement.	86
3.23	Emission spectra of Mn ²⁺ and Tb ³⁺ -doped FP1 glass compared with the transmission spectrum for a 3 mm thick Schott BG39 filter.	87
4.1	Cross-section of the extrusion process. This diagram shows only the inner section of the setup, surrounding the body is a furnace, which is controlled using feedback from the thermocouple. The puncher enters through the top of the furnace, and the extruded preform exists through the bottom.	90

4.2	Preform surface quality following extrusion through Macor® at 525 °C at speeds of (left) 0.2 mm/min and (right) 0.1 mm/min.	93
4.3	Effect on FP1 glass of heating to 525 °C in a furnace. Left: unheated sample of FP1 glass, right: FP1 glass following heating to 525 °C.	94
4.4	Composition of optical fibre preform surface compared with the bulk material, measured using the scanning electron microscope on EDX mode.	95
4.5	Examples of surface defects taken using the Optical Profiler using VSI mode. Note the colour-coded height scales can change significantly, based on the scale of the surface measured.	96
4.6	Etching efficiency of fluoride phosphate glass by 0.6 M AlCl ₃ in 1M HCl, etching efficiency in mg/min is calculated from the slope.	97
4.7	Surface profile of a fluoride phosphate preform showing (a) unetched and (b) etched surfaces.	98
4.8	Surface of preform throughout the polishing process. Time = (a) 0 min (b) 10 min (c) 30 min (d) 90 min	99
4.9	Surface roughness with respect to the polishing time of an FP preform surface with colloidal silica. Lines are included only as a guide for the eye.	100
4.10	Comparison of neckdown region between (a) unpolished and (b) polished preforms. All other fabrication conditions were constant.	104
4.11	Neckdown region of fluoride phosphate fibre preform remains imaged with an optical profiler. The surface layer has been drawn into a corrugated structure. The fibre drawing direction is in line with the corrugations and toward the bottom of the figure.	104
4.12	Loss in undoped fluoride phosphate optical fibres.	105
4.13	Loss of selected undoped FP1 optical fibres at 550 nm. Polishing of fibre preforms was commenced for fibre trial F11. Due to high loss or fibre pull failure, not every fibre trial result can be shown. In two cases (F12 and F13)) preforms were drawn down into canes, not fibres, hence no loss result is shown.	106
4.14	Loss of fluoride phosphate optical fibres fabricated from polished preforms extruded through Macor® and stainless steel.	106
4.15	Tb ³⁺ -doped FP glass billet, polished in preparation for extrusion. Tb ³⁺ -concentration is 7200 ppmwt, billet mass is 102.6 g.	109

4.16	Comparison of loss in undoped and Tb ³⁺ -doped fluoride phosphate optical fibres. Optical fibres were fabricated from glasses melted in both oxidising and reducing atmospheric conditions. F15: Undoped, F17: Tb ³⁺ -doped 7200 ppmwt reducing atmosphere, F18: Tb ³⁺ -doped 720 ppmwt reducing atmosphere, F19: Tb ³⁺ -doped 7200 ppmwt oxidising atmosphere	109
4.17	Crystalline and bubble defects in Tb ³⁺ -doped FP preform (E17). Several lines of black crystalline defects were observed to reach lengths of approximately 5 - 10 mm.	110
4.18	Absorbed energy comparison of (a) 2.28 MeV beta particles and (b) 2.28 MeV photons within a 160 µm thick slab of FP glass with PVC layers of varying thickness.	111
5.1	Dose comparison in a 160 µm thick slab of FP glass with and without an aluminium backing.	116
5.2	TL Calibration curve of dose delivered to a 7.5 mm Tb ³⁺ -doped FP1 fibre section.	119
5.3	Transmission spectra of dichroic filters used for isolation of the luminescence signal from the optical stimulation. Note that for the 800 nm dichroic, the stimulation laser is reflected and the luminescence signal is transmitted through to the detector; for the 505 nm dichroic, the stimulation laser is transmitted and the luminescence signal is reflected toward the detector.	120
5.4	Transmission spectra of individual coloured glass filters used in the Risø Reader and for OSL tests on the experimental test-bed. The Schott BG3 filter is 3 mm thick, the Hoya U340 is 7.5 mm thick, the Corning 7-59 is a stack of 3 mm and 4 mm filters totalling 7 mm in thickness, the necessary thickness to adequately suppress scattered photons at 532 nm. For suppression of scattered photons at 852 nm, a BG39 filter 3mm thick is sufficient.	120
5.5	Output spectra of the lasers used for OSL measurements in optical fibres.	122
5.6	Transmission spectra of the individual coloured glass (3 mm thick) and interference filters used for OSL measurements.	123
5.7	Suppression of the 700 - 1100 nm transmission window with composite filters. Composite filters are constructed by stacking a BG39 filter with 700 and 800 nm short pass interference filters, and also separately with a Schott BG39 filter. The Schott BG3 and BG39 filters are both 3 mm thick.	124

5.8	Experimental setup for the detection of OSL from a coiled fibre bundle with a PMT, the optical stimulation at 532 nm is shown in green, luminescence is shown in violet.	129
5.9	OSL response from bundles of 160 μm diameter FP optical fibres, increasing the number of fibres in the bundle increases the OSL intensity. No observable OSL was measured from a single fibre at this stage. The shutter for optical stimulation was operated manually, hence OSL is observed at slightly different times from the onset of data acquisition. Lines are included only to assist in distinguishing the data.	129
5.10	OSL signal from a fibre bundle. Each measurement is taken with a different number of total fibres in the bundle.	130
5.11	Isolation of the detector from scattered photons decreases the background noise; scattered photons are due to both ambient light sources and the laser optical stimulation. In addition, performing experiments in black-out conditions reduces the background further. Data was taken from two different optical fibres, therefore light sums should not be directly compared, the data serves as a demonstration of background counts.	131
5.12	RL and OSL signals from a bundle of FP1 optical fibres, each of which are marked on the plot. Irradiation is from a $^{90}\text{Sr}/^{90}\text{Y}$ beta source, optical stimulation at 532 nm, detection with an EMI 9635 QA PMT using a 4 mm Corning 7-59 filter.	132
5.13	Sample holder designed to hold an optical fibre coiled in a near light-tight environment underneath a $^{90}\text{Sr}/^{90}\text{Y}$ beta source. It is machined from aluminium in order to provide a material with low Z number for conversion of beta particles into low-energy bremsstrahlung emission. Red lines indicate the position of a fibre in the holder without the cover plate (left), and the holder is also shown with its cover plate and the beta source in position (right).	133
5.14	Schematic representation of the set-up for a fibre bundle and a cane. . .	134
5.15	Experimental setup for the detection of OSL from glass canes using a PMT. The optical stimulation at 532 nm is shown in green, luminescence is shown in violet, the 405 nm laser used to assist optical alignment is shown in blue.	134
5.16	OSL response from a 1 mm FP cane compared with a bundle of 32, 160 μm diameter FP fibres. In order to compare the results here, data has been normalised for the bin time of data collection: a 100 ms bin time was used for the bundle, 1 ms was used for the cane.	135
5.17	Alignment control of fibre output onto the 50 μm SPAD detector chip. .	136

5.18	OSL in FP glass with respect to stimulation laser power at 532 nm. . .	138
5.19	OSL response of FP1 glass cane with respect to $^{90}\text{Sr}/^{90}\text{Y}$ exposure time.	139
5.20	OSL response of FP1 glass cane with respect to activity of the $^{90}\text{Sr}/^{90}\text{Y}$ beta source.	139
5.21	OSL response of canes with respect to diameter. Dose was approximately 14.5 ± 0.5 Gy.	141
5.22	Experimental setup for the detection of OSL from a single optical fibre using a SPAD.	141
5.23	Experimental setup for the detection of OSL from glass canes using a SPAD. Optical stimulation at 852 nm is shown in red, luminescence is shown in teal, the 532 nm laser used to assist optical alignment of the system is shown in green.	143
5.24	OSL response of Tb^{3+} -doped fibres/canes with respect to diameter. De- tection was by a SPAD optically filtered by a 3 mm Schott BG39 filter. Dose was approximately 14.6 ± 0.5 Gy.	143
5.25	Normalised OSL measurements with respect to the position of the $^{90}\text{Sr}/^{90}\text{Y}$ radiation source along glass canes measured from the cane output, cane diameter is 1000 μm . Measurements were taken in the 350 – 600 nm wavelength region using a Schott BG39 filter and optical stimulation at 852 nm.	144
5.26	Experimental setup for the detection of OSL from a single optical fibre using a SPAD.	145
5.27	Normalised OSL measurements with respect to the position of the $^{90}\text{Sr}/^{90}\text{Y}$ radiation source along glass canes measured from the fibre output. Mea- surements were taken in the 350 – 600 nm wavelength region using a Schott BG39 filter and optical stimulation at 852 nm.	145
5.28	Experimental setup for the detection of OSL from a single optical fibre using a SPAD.	147
5.29	Schematic representation showing the X-ray beam divergence and the position of the fibre coil in the X-ray beam.	149
5.30	Example of a TL calibration curve of dose delivered to an $\text{Al}_2\text{O}_3:\text{C}$ dosimeter chip in order to calculate an equivalent dose.	149
5.31	X-ray Beam profile obtained from placing $\text{Al}_2\text{O}_3:\text{C}$ dosimeter crystals at certain x, y positions in the X-ray beam. The dose absorbed by each chip is then calculated from the TL intensity, normalised for the TL response of each individual chip.	150

5.32	X-ray imaging plate exposed to the X-ray beam in order to visualise the beam intensity profile. Beam attenuation is observed on the right hand side due to the X-ray Head handle. No significant fluctuation of beam intensity is observed in the central area where optical fibres are positioned.	151
5.33	Photodarkening of FP fibres during X-ray exposure, shown by the diminishing transmission of 532 nm laser photons through the fibre under irradiation during the laser illumination. The plot showing cycled exposure clearly demonstrates the scintillation signal detected during irradiation cycles.	153
5.34	OSL from 200 μm fibre (F16) as a function of photon beam intensity at 100 and 300 kV tube potentials.	154
5.35	OSL response of 160 μm fibres (F16) with respect to X-ray tube potential at a constant beam intensity of 180 mAs.	155
5.36	PENELOPE simulation of absorbed energy as a function of initial photon energy in FP glass.	156
5.37	OSL from 160 μm fibre (F16) as a function of X-ray tube potential at a constant beam intensity of 60 mAs. Aluminium cover plate has been replaced with black tape.	157
6.1	Comparison of OSL from high purity (LWQ) and ultra-high purity (F300) silica glasses. Results are taken using two stimulation wavelength and filter combinations: 870 nm stimulation with a Schott BG39 filter, and 470 nm stimulation with a HOYA U340 filter.	163
6.2	Reproducibility of silica samples LWQ, MCVD1 and MCVD2 glass in the 350 - 600 nm waveband, a Schott BG39 filter and 870 nm optical stimulation. Results are given for different bleaching times between measurements, 5 s and 30 s, the optical power incident on each sample is shown by the graph titles. Lines are provided only as a guide for the eye.	164
6.3	Thermoluminescence of silica glass samples. TL from undoped FP glass is also provided for comparison. No filters were used for TL here, in order to reveal total light sums.	165
6.4	Thermoluminescence emission spectra of samples LWQ, MCVD1 and MCVD2, 3D and intensity contour plots. $^{90}\text{Sr}/^{90}\text{Y}$ irradiation time is 300 s, and the heating rate was 5 K/s.	166
6.5	Initial rise thermoluminescence for LWQ silica. Measurements followed the procedure described previously in Section 2.6.1. Values of T_m given in the legend are in $^{\circ}\text{C}$.	167

6.6	Comparison of LWQ and FP glass optical fibres. Both undoped (F15) and Tb ³⁺ -doped (F19) FP fibres are provided. The bare silica fibre fabricated for this project (LWQ Silica) is compared with the loss of another fibre fabricated from the same glass for a different project (LWQ Silica WW 10 µm). This demonstrates the high loss measured for LWQ Silica, at 0.4 - 0.5 dB/m, higher than the expected 0.1 dB/m observed in the fibre LWQ Silica WW 10 µm. The expected H ₂ O peak at approximately 1400 nm is observed for both silica fibres.	170
6.7	OSL intensity with respect to the position of the ⁹⁰ Sr/ ⁹⁰ Y beta radiation source along LWQ silica cane (top) and fibres (bottom). Lines are included only as a guide for the eye.	172
6.8	Dose dependence of OSL from 1 mm diameter LWQ silica cane. Detection using a PMT, optical stimulation at 532 nm and filtration with a Schott BG3.	173
6.9	Dose dependence of OSL from 1 mm diameter LWQ silica cane. Detection using a SPAD, optical stimulation at 852 nm and filtration with a Schott BG39.	174
6.10	Dose dependence of OSL from 1 mm diameter LWQ silica cane. Detection using a SPAD, optical stimulation at 852 nm and filtration with a Schott BG39. Variation in dose is due to the activity of the ⁹⁰ Sr/ ⁹⁰ Y beta source. Inset: results were also recorded for the RL with respect to activity of the ⁹⁰ Sr/ ⁹⁰ Y beta source.	174
6.11	OSL response of LWQ silica fibre with respect to beam intensity at tube potentials of 100 and 300 kV.	175
6.12	OSL response with respect to X-ray tube potential using LWQ silica optical fibres of varying diameter. Optical stimulation at 852 nm, using a Schott BG39 filter. Lines are included only as a guide for the eye. . .	177
6.13	Simulation showing energy absorbed (dose) by silica fibre with respect to X-ray photon energy.	177
6.14	OSL response with respect to X-ray tube potential at a beam intensity of 600 mAs. Measurements taken without the aluminium lid of the fibre holder.	178
6.15	(a) OSL response with respect to thickness of aluminium shielding between the X-ray source and the fibre. (b) Simulation of absorbed energy in an FP glass volume behind aluminium layers of varying thickness using PENELOPE. Several different initial photon energies were simulated.	179

6.16	Plot of the OSL data provided in Table 6.7, shown for both 275 – 400 and 350 – 600 nm wavelength regions. OSL results for silica glasses are compared with selected FP samples, both doped and undoped.	183
7.1	(a) Potential design of a field-portable fibre dosimetry test kit. (b) Potential design of a field-portable fibre dosimetry test kit with integrated stimulation laser and ‘lens-filter’. (c) Field-portable OSL test rig without free-space optics, where all elements are fibre-coupled.	196
A.1	Loss of LWQ silica optical fibres with wagon wheel microstructured geometry.	220
A.2	Electron mean free path and range in fluoride phosphate glass.	221
A.3	Electron mean free paths in fluoride phosphate glass.	221
A.4	Electron Stopping Powers in fluoride phosphate glass.	222
A.5	Electron Cross Sections in fluoride phosphate glass.	222
A.6	Photon mass attenuation coefficients in fluoride phosphate glass.	223
A.7	Photon Mean Free Paths in fluoride phosphate glass.	223
A.8	Photoelectric cross-section ceiling in fluoride phosphate glass.	224
A.9	Rayleigh cross-section ceiling in fluoride phosphate glass.	224
A.10	Photon Cross Sections in fluoride phosphate glass.	225
B.1	Schematic diagram of a Risø DA-20 TL/OSL Reader, showing both the irradiation and luminescence detection functions.	228
B.2	Glass melting facilities. Top: nitrogen atmosphere glovebox for batching and melting of fluoride glasses. Bottom: open air melting and annealing furnaces.	229
B.3	Crucibles and glass moulds used for remelting and doping of FP glasses. Vitreous carbon crucibles are used for reducing environment melts; the platinum crucible is used for open air, oxidising environment melts. Brass moulds are polished before use.	230
B.4	Soft glass extrusion machine, used for all extrusions of fluoride phosphate preforms. The inside of the body is shown by a cross section diagram in Section 4.2, Figure 4.1.	231
B.5	Soft glass optical fibre draw tower.	233
D.1	Comparison of stopping power values for electrons in water, calculated using PENELOPE and ESTAR.	236
D.2	Comparison of stopping power values for electrons in aluminium, calculated using PENELOPE and ESTAR.	237

D.3	Comparison of stopping power values for electrons in fluoride phosphate glass, calculated using PENELOPE and ESTAR.	237
D.4	Simulated energy of transmitted primary particles from a 2.28 MeV electron beam (left) and a 100 keV photon beam (right) by layers of FP glass with varying thickness. Simulation was performed using PENELOPE. .	238

List of Tables

1.1	$^{90}\text{Sr}/^{90}\text{Y}$ Radiation Sources Used for Optical Fibre OSL Experiments. . .	20
1.2	Comparison of specifications for an EMI 9235 QB photomultiplier tube and two SPADs, a Lasercomponents COUNT [®] -Blue and a Micro Photon Devices PDM.	26
2.1	Representative selection of fluoride phosphate glass samples analysed for their luminescence behavior.	33
2.2	Composition of several fluoride phosphate glasses as determined by analysis with an electron microprobe.	35
2.3	ICPMS/OES analysis of fluoride phosphate glass samples. The concentration, c (ppm), of impurity ions is shown.	37
2.4	Effect of glass fabrication atmosphere on the OSL response of fluoride phosphate glasses	41
2.5	Activation Energy (E), Frequency Factor (s) and Lifetimes at $T = 293$ K (τ) for FP1 glass using initial rise data.	45
3.1	Representative selection of doped fluoride phosphate glass samples. Atmosphere refers to the conditions in which the glass was melted: the label ‘ox’ corresponds to an ambient atmosphere containing oxygen; the ‘red’ label corresponds to a controlled glovebox atmosphere purged with nitrogen, creating reducing conditions.	63
3.2	Activation energy (E), frequency factor (s) and lifetimes at $T = 293$ K (τ) of sample Mn-ox.	73
3.3	Activation energy (E), frequency factor (s) and lifetimes at $T = 293$ K (τ) of sample Tb-red.	78
3.4	OSL response of doped and undoped FP1 glass, fabricated under both oxidising and reducing conditions, integrated from 0 - 0.2 s. 275 – 400 nm indicates OSL in this wavelength region, achieved using a HOYA U340 filter and 470 nm stimulation. 350 – 600 nm indicates emission in this wavelength region achieved with a Schott BG39 filter and 870 nm stimulation.	82

4.1	Summary of solutions trialled for etching of fluoride phosphate glass . . .	98
5.1	Composition of FP1 glass, the molecular weight and stopping power of each element is listed along with the atomic percentage of the element in the material.	117
5.2	Distance along a Tb ³⁺ -doped fibre at which an OSL signal is measurable using an absorbed dose of 14.6 ± 0.5 Gy from a ⁹⁰ Sr/ ⁹⁰ Y beta source. Measurements were performed using both wavelength regimes: stimulation at 532 nm using a Schott BG3-BG39 filter stack and stimulation at 852 nm using a Schott BG39 filter.	147
6.1	Silica glass samples analysed in this chapter.	161
6.2	OSL response of LWQ and F300 silica glasses, taken for both wavelength regions using either a HOYA U340 filter or a Schott BG39. Beta irradiation applied for 10 s, and OSL intensities are normalised for mass. . . .	162
6.3	Activation Energy (E), Frequency Factor (s) and Lifetimes at $T = 293$ K (τ) for LWQ silica using initial rise data.	168
6.4	Activation Energy (E), Frequency Factor (s) and Lifetimes at $T = 293$ K (τ) for MCVD1 silica using initial rise data.	168
6.5	Activation Energy (E), Frequency Factor (s) and Lifetimes at $T = 293$ K (τ) for MCVD2 silica using initial rise data.	169
6.6	Length of silica fibre at which an OSL signal is measurable using an absorbed dose of 15.5 ± 0.5 Gy from a ⁹⁰ Sr/ ⁹⁰ Y beta source. Measurements were performed using both wavelength regimes: stimulation at 532 nm using a Schott BG3-BG39 filter stack, and stimulation at 852 nm using a Schott BG39 filter.	171
6.7	OSL response of silica glasses compared with doped and undoped FP1 glass, fabricated under both oxidising and reducing conditions, integrated from 0 - 0.2 s. ‘275 – 400 nm’ indicates OSL in this wavelength region, achieved using a HOYA U340 filter and 470 nm stimulation. ‘350 – 600 nm’ indicates emission in this wavelength region achieved with a Schott BG39 filter and 870 nm stimulation.	183
A.1	Example of purity of commercial silica glasses. Data taken from Heraeus Quarzglass.	219